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THE CURRENT STATE OF THE PROBLEM OF NUMERICAL INVESTIGATION OF METAL STRUCTURE REFUSAL BASED ON DYNAMIC MONITORING

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This article examines the current state of the problem of failure of metal structures in the construction industry, focusing on dynamic monitoring. The concept of rejection is defined; its history and importance for the environment and society are considered. The process of monitoring building structures, including dynamic monitoring, its significance and advantages, are considered in details. Advantages and disadvantages of different approachesto dynamic monitoring are discussed. Modern research related to dynamic monitoring, one of the algorithms used, is considered.
Keywords: dynamic monitoring, failure of building structures, loss of bearing capacity, metal structures, element failure, numerical studies, reliability.

Introduction. Engineering and construction infrastructure is usually the most expensive national investment and asset of any country. In addition, engineering structures have a long lifespan compared to other commercial products and they are expensive to maintain and replace after construction. Also, in civil engineering, there are multiple prototypes and each structure becomes unique in terms of materials, design and construction. The most important structures include bridges, high-rise buildings, energy networks, nuclear power plants and dams. All civil structures age and deteriorate over time. Deterioration is mostly the result of aging materials, constant use, overloading, aggressive exposure conditions, lack of proper maintenance, and difficulties in proper inspection methods. All of these factors contribute to material and structural degradation as internal and external damage occurs and combines, then develops and progresses.

In the modern world, the use of metal structures in construction and industry is growing rapidly. With this growth comes the question of their reliability and safety in operation. With the increase in the size and complexity of structures, there is an urgent need to study the risks of failure to prevent possible accidents and ensure the stability of infrastructure objects.

The object of researchisthe failure of building structures, and the subject is the risks of failure of metal structures. During the research, the authors concentrate on aspects that affect their functionality and safety. The purpose of the study is a literature review of the sources of development and application of numerical methods for assessing the risks of failure of metal structures, in particular, using dynamic monitoring. As well as creating effective tools for predicting possible problems and improving their reliability.

Analysis of literary data. Problem setting. Failure of building structures - is the process of them losing their bearing capacity or functionality as a result of loads, environmental influences, damage, defects, aging, etc.

In the period of development of construction, specialists first encountered problems in structures, defining them as "failures". This could refer, for example, to the collapse of a wall or the loss of stability of a roof. Over time, with the increasing complexity of construction projects, professionals have improved their methods of detecting and managing failures.

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The failure of building structures can have various consequences for the safety of people, property, the environment and the economy. Therefore, it is important to ensure the reliability and structural safety of buildings and structures at all stages of their life cycle [1].

The reliability and structural safety of buildings and structures depend on many factors, such as the choice of materials, design, implementation, operation, maintenance, repair, reconstruction, liquidation, etc. For each of these factors, there are relevant regulatory documents, methods of calculation, control, assessment and risk management [1].

To classify building structures according to the degree of their responsibility and requirements for reliability and safety, such concepts are used as categories of responsibility, classes of consequences, classes of loads, classes of fire resistance, limits of the spread of fire, etc. [2, 3].

To analyze the causes and mechanisms of failure of building structures, various methods are used, such as expertise, diagnostics, monitoring, modeling, experiment, statistics, etc. [1].

Further failure research aims to use the latest technologies and innovations in the construction industry to improve the understanding and management of risk. The study of the term "failure" in construction appears to be key to the stability and safety of building structures. The emergence and development of this concept indicates the evolution of approaches in the construction industry and the constant desire to improve the quality and reliability of buildings.

Monitoring of building structures - is a process of long-term observation of their technical condition, load-bearing capacity, deformations, damage, etc. Monitoring may be necessary to ensure the safety, reliability, energy efficiency and durability of buildings and structures, especially in cases of construction in difficult conditions, the presence of defects or landslides.

Monitoring usually includes the following main stages:

- Conducting initial geodetic monitoring regarding the degree of deformation of objects and other indicators;
- Visual inspection of the structure of buildings, identification and classification of their defects and damage;
- Instrumental examination of building structures with determination of deviation of their individual parts, presence of cracks, strength of concrete, thermal radiation, etc.;
- Installation of combined beacons in places where cracks are detected and assessment of their changes during the monitoring process;
- Determination of the integral characteristic of the state of the load-bearing structures in relation to external influences, such as deformation energy, oscillations, damping coefficients, etc.;
- Provision of periodic conclusions and recommendations on ensuring the strength and stability of structures, including instructions on the arrangement of temporary supports and reinforcements, requirements for the magnitude of installation loads and impacts.

Monitoring allows identifying and evaluating defects, damage, deformations, stresses, fluctuations, environmental influences and other parameters that characterize the operation of structures. Monitoring also helps predict the development of failure, prevent emergency situations, and develop measures for maintenance, repair, strengthening, reconstruction and liquidation of structures.

Monitoring of building structures can be carried out at various stages of the object's life cycle: design, construction, operation, reconstruction, liquidation. Monitoring can also be classified by level of complexity, frequency of execution, measurement methods, and types of structures, goals and objectives.

Monitoring of building structures is required for the third stage of consequence (responsibility) objects in accordance with Ukrainian building regulations, the destruction of which can lead to catastrophic consequences [**Ошибка! Источник ссылки не найден.**].

Dynamic monitoring of building structures. For the monitoring of building structures, the main, until recently, was the use of static deformation indicators of objects: movements, angles of inclination, rotation, etc. A typical example of such control can be the automated system of static monitoring of the building structure of the International Exhibition Center, created by the SOLDATA company [5]. But, as experience shows, the peculiarities of this monitoring and its technical support characterize only the condition of individual constructions of the building. Their results cannot be extended even to similar structures of this building that are not controlled. Another drawback is the intuitive definition of control (monitoring) points.

Dynamic monitoring of building structures is a type of monitoring that takes into account dynamic loads acting on structures during operation, such as wind, traffic, seismicity, explosions, etc. Dynamic monitoring allows determining the dynamic characteristics of structures, such as frequencies, forms and amplitudes of natural oscillations, damping coefficients, critical speeds, resonance phenomena, dynamic coefficients, etc. Dynamic monitoring also helps to detect dynamic structural defects and damage such as cracks, breaks, loss of stiffness, reduced damping, geometry change, etc.

Dynamic monitoring of building structures has a number of advantages, such as:

- Ability to evaluate the dynamic behavior of the structure in real operating conditions, not only in laboratory conditions;
- Ability to detect dynamic defects and damage that may be invisible during static monitoring;
- Ability to use dynamic monitoring as a means of diagnosis, forecasting and control of the technical condition of structures.

Therefore, it is more promising to use dynamic monitoring, the indicators of which reflect the global state of the building and allow monitoring the state of its individual structures. This is, first of all, the determination of the value of natural frequencies [6], the forms of natural oscillations and the values of the logarithmic decrement of their attenuation.

The main types of dynamic monitoring of building structures:

- Seismic monitoring - assessment of the impact of earthquakes on buildings and determination of their resistance to seismic events;
- Vibration monitoring - observation and measurement of vibrations that may be caused by traffic, machine operation or other dynamic factors:
- Monitoring of wind loads - determining the impact of wind on buildings and assessing their resistance to wind loads:
- Acoustic monitoring - measurement of sound waves that may indicate dynamic events or problems in structures:
- Monitoring of traffic loads - observation of the impact of traffic on nearby buildings and infrastructure.

Modern researches based on dynamic monitoring. In-service monitoring, measuring the behavior of structures under the influence of operational loads and environmental conditions, has undergone rapid development over the past 20 years due to reduced equipment costs, increased durability and sensitivity of monitoring technology, and increased computing and data storage capabilities. These developments have largely focused on the potential benefits that in-situ monitoring can offer for condition assessment, damage detection and structural health monitoring [7], however, recent research has begun to explore the potential of long-term monitoring to inform the design of civil structures. Updating finite element models based on measured in-service performance offers a direct way to compare the predicted behavior of a structure with its in-service behavior. However, few works have explored the industry's perception of how long-term in-service monitoring can be used to influence and improve the civil and construction engineering design process.

For example, in [8], the dynamic analysis of the structure was carried out using the SSI-Cov algorithm. The method begins with a pre-processing stage, in which the correlation matrix of the received signals is determined using the so-called "Welch estimate" or periodogram approximation. First, the signals were divided into small blocks with 50% overlap and “Hanning windows” in mind. A discrete Fourier transform (1) and an average correlation matrix (2) were calculated for each of them

$$Y_b(\omega_j) = \sum_{k=0}^{n-1} \omega_k y_{b,k} e^{-k\omega_j k\Delta t}, \tag{1}$$

$$\widehat{S}_{yy}(\omega_j) = \frac{1}{n_b} \sum_{b=1}^{n_b} Y_b(\omega_j) Y_b(\omega_j). \tag{2}$$

The SSI-Cov method is based on model identification using the state variables included in the spatial state model presented in (3) and (4):

$$\dot{x}(t) = \mathbf{A}x(t) + \mathbf{B}u(t), \tag{3}$$

$$\dot{y}(t) = \mathbf{C}x(t) + \mathbf{D}u(t), \tag{4}$$

where $\dot{x}(t)$ is the state vector; $\dot{y}(t)$ is the output vector; u(t) is thecontrol vector; **A** – state matrix; **B** – input matrix; **C** - output matrix; and *D* - is a direct matrix. The modal parameters can be obtained from (5), where Ψ is the matrix of eigenvectors, and Λ is the matrix of eigenvalues:

$$\mathbf{A} = \Psi\Lambda\Psi^{-1}. \quad (5)$$

Recent failure studies of steel structures have shown that they are highly susceptible to damage and therefore prone to potential local or total failure. Many authors recommend monitoring critical elements in existing steel structures in real time to predict any defects in local elements.

All research in long-term monitoring is mostly focused on the potential benefits of monitoring in fault detection and structural condition monitoring [9]. This aspect emphasizes the need to establish management and maintenance procedures to maximize life cycle and obtain optimal return on investment.

Keeping structures in good condition ensures people's safety and can help avoid structural collapses, such as the Viadotto Polchevera collapse in Genoa, Italy in 2018, which killed 43 people. Other similar disasters include the Florida International University Pedestrian Bridge in 2018 (Fig. 1), the Xinjia Express Hotel in 2020, which killed 29 people, or the I-35 W Bridge over the Mississippi River, an eight-lane steel truss arch bridge that collapsed in evening rush hour, resulting in over 100 vehicles and 13 people being injured.

Fig. 1. Pedestrian bridge collapse in Miami, Florida. 2018

A US study of steel truss railroad bridges [10] found more than 500 failures over 11 years (1989–2000), showing that these failures are by no means uncommon (an average of 9.7 bridges per year in the US) and that these bridges very impressionable. A common feature is that local failure initiates the progressive collapse of the entire structure or at least a significant part of it. Although research on the progressive collapse of buildings is quite extensive, the same cannot be said for truss structures. There is still a long way to go in studying the structural behavior of truss structures after local failure and making practical recommendations for monitoring bridges currently in operation.

The bibliography shows that valuable information about structural behavior can be obtained through long-term monitoring. Some examples given in the literature show the advantages of establishing long-term monitoring for a better assessment of the condition of the structure.

Of all the variables that provide information about structures, vertical deflections and modal frequencies best represent the overall behavior of the structure. As a rule, the measurement of these variables involves the use of sensors connected by wires to monitoring systems.

Conclusion. If to extrapolate the conclusions obtained in the cited literature sources, it can be noted that a monitoring strategy based on strain sensors requires a large number of elements, which, as a rule, involves high economic, technical and labor costs, as can be seen from real cases.

Currently, engineering practice does not have at its disposal single universal methods of monitoring construction objects. And the existing ones in a number of cases do not take into account the structural and technological features of buildings and have a limited informational nature.

This especially applies to spatial constructions, in which the problem of monitoring is practically not solved. These buildings are characterized by their large size, significant structural filling, various types of structural elements and other features. This category of objects is widely spread in practice. It includes objects of industrial infrastructure, exhibition centers, air and railway terminals, large shopping and entertainment complexes, sports arenas and others.

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СУЧАСНИЙ СТАН ПРОБЛЕМИ ЧИСЕЛЬНОГО ДОСЛІДЖЕННЯ МЕТАЛОКОНСТРУКЦІЙ НА ОСНОВІ ДИНАМІЧНОГО МОНІТОРИНГУ.

У статті розглядається критична роль тривалого динамічного моніторингу будівельних конструкцій у забезпеченні їх безпеки та стійкості. Підкреслено важливість вивчення структурної поведінки фермових конструкцій після локальних руйнувань, що є ключовим для розробки ефективних методів моніторингу. Вказується значення вертикальних відхилень і модальних частот як індикаторів загальної поведінки конструкцій, а також високі витрати, пов'язані з традиційними методами моніторингу, що вимагають великої кількості датчиків. Наголошується, що сучасна інженерна практика не має універсальних методів моніторингу, які б враховували всі особливості будівельних конструкцій, особливо просторових споруд зі складною конструкцією та різноманітністю елементів. Автори закликають до розробки нових підходів і технологій для покращення моніторингу та управління ризиками, які можуть запобігти катастрофічним наслідкам, як це було у випадку з Viadotto Polchevera та іншими конструкційними руйнуваннями. Звертається увага на сучасні дослідження, які використовують динамічний моніторинг для інформування при проектуванні цивільних конструкцій, включаючи оновлення моделей скінченних елементів на основі виміряних експлуатаційних характеристик. Підкреслюється, що тривалий моніторинг може надати цінну інформацію про поведінку конструкції, що дозволяє краще оцінити стан конструкції та передбачити потенційні дефекти. Наголошується, що локальний збій може призвести до прогресуючого руйнування всієї конструкції, що робить моніторинг надзвичайно важливим для запобігання подібних інцидентів. Стаття завершується висновками про необхідність встановлення процедур управління та обслуговування для максимізації життєвого циклу конструкцій та отримання оптимального повернення інвестицій.

Ключові слова: динамічний моніторинг, відмова будівельних конструкцій, втрата несучої здатності, металоконструкції, відмова елемента, чисельні дослідження, надійність.

Vabishchevych M.O.,Dedov O.P., Savchuk D.O.

THE CURRENT STATE OF THE PROBLEM OF NUMERICAL INVESTIGATION OF METAL STRUCTURE REFUSAL BASED ON DYNAMIC MONITORING.

The article considers the critical role of long-term dynamic monitoring of building structures in ensuring their safety and stability. The importance of studying the structural behavior of truss structures after local failures is emphasized, which is key to the development of effective monitoring methods. The value of vertical deflections and modal frequencies as indicators of the general behavior of structures is pointed out, as well as the high costs associated with traditional monitoring methods requiring a large number of sensors. It is also emphasized that modern engineering practice does not have universal monitoring methods that would take into account all the features of construction structures, especially spatial structures with a complex design and a variety of elements. Authors calls for the development of new approaches and technologies to improve risk monitoring and management, which can prevent catastrophic consequences, as was the case with Viadotto Polchevera and other structural collapses. Attention is also drawn to current research that uses dynamic monitoring to inform the design of civil structures, including updating finite element models based on measured in-service performance. It is highlighted that long-term monitoring can provide valuable information about structural behavior, which allows for a better assessment of the condition of the structure and the prediction of potential defects. It is emphasized that a local failure can lead to the progressive destruction of the entire structure, which makes monitoring extremely important to prevent such incidents. The article concludes with conclusions about the need to establish management and maintenance procedures to maximize the life cycle of structures and obtain optimal return on investment.

Keywords: dynamic monitoring, failure of building structures, loss of bearing capacity, metal structures, element failure, numerical studies, reliability.

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Вабіщевич М.О., Дєдов О.П., Савчук Д.О. **Сучасний стан проблеми чисельного дослідження металоконструкцій на основі динамічного моніторингу**// Опір матеріалів і теорія споруд: наук.-техн. збірник. – К.: КНУБА, 2024. – Вип. 112. – С. 52-57. – Англ.
У статті наводяться літературний огляд сучасного стану досліджень будівельних конструкцій на основі динамічного моніторингу, що буде корисним для інженерів-проектувальників та студентів будівельних спеціальностей ВНЗ.
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The article provides a literature review of the current state of investigation of metal structure refusal based on dynamic monitoring, which will be useful for design engineers and students of construction specialties of universities.
Fig. 1. Ref. 10.

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